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Strategies in membrane emulsification to make the process suitable for industrial application

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There is increasing interest in the use of emulsion based end-products with target size, composition, structure and function in medical, pharmaceutical, biotechnological, chemical and food industry. At the same time, there is a need for precise, controlled manufacturing processes able to reduce energy consumption, increase productivity and improve products quality.

Membrane emulsification is a promising technology for the production of micro-nano dispersed materials. The main advantages of membrane emulsification process compared to the conventional mechanical emulsification processes (ultrasound, high-pressure systems, rotor-stator systems) are the low energy consumption per unit of product made with high energy efficiency, quality and functionality of delicate used ingredients and the precise manufacture of emulsions with controlled droplets size and size distribution.

A considerable challenge in membrane emulsification remains in obtaining emulsions having a narrow droplet size distribution at high dispersed phase fluxes (productivity) sufficiently to make the process suitable for industrial application. The interaction between the disperse phase and the membrane pore wall is a significant factor in the productivity enhancement. The membrane pore wall having good wettability to the disperse phase allows the oil phase to permeate more quickly in the pores, and hence results in significantly higher productivity. However, to obtain emulsion with controlled size and size distribution is important that the membrane not be wetted by the phase to be dispersed: hydrophilic membranes are used in the preparation of O/W emulsions and hydrophobic membrane in the preparation of W/O emulsions and low dispersed phase flux value are usually obtained. As yet little has been done to find ways of overcoming this problem and limiting the increase in droplet size at higher dispersed phase fluxes, which is necessary if industrial-scale production is to be realized, especially for submicron droplets. Another important point in membrane emulsification process is to control the shear stress conditions especially if larger droplets, bioactive functionalized particles or viscous dispersed materials like o/w, o/w/o emulsions, polymer-based materials are produced. The high shear stress required to obtain particles with controlled size and size distribution some time determine the break-up of the droplets previously formed within the pump and fitting or deactivation of biofunctional compounds especially in cross-flow system or in the paddle stirred system in stirred membrane emulsification. On the other end, despite the other techniques existing in the literature for the creation of monodisperse emulsions, cross-flow membrane emulsification is a suitable method for industrial scale applications because permits to operate under continuous mode operation and could be scaled up to industrial scale machines. The aim of this work is to introduce new strategies in cross-flow membrane emulsification method to promote the use of membrane process in industrial particles production by increasing the productivity of the process and decrease the shear stress conditions.

The use of a membrane having asymmetric properties in terms of wettability between shell and lumen side was tested in the preparation of W/O emulsions as a method to increase dispersed phase flux (and process productivity). The membrane wettability modification by protein adsorption was used to obtain a hydrophilic membrane with asymmetric properties. A ceramic membrane having 50 nm as pore size was used and protein adsorption method was selected to obtain membrane-protein interaction. Preliminary investigations are carried out to evaluate the adsorption phenomena as a function of: protein parameters (concentration, chemical-physical properties), membrane parameters (pore size, wettability), operating parameters (flow rate). The W/O emulsion prepared following membrane modification was compared with the W/O emulsion prepared without membrane modification. W/O emulsion particles with smaller droplets size and

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size distribution compared with the non-modified hydrophilic membrane were obtained. When modified membrane was used, droplets of 8 μm and span of 1 were obtained while droplets size and span were, respectively, 24 μm and 1.6 when a membrane without modification was used. A dispersed phase flux of 30 l/hm^2 was obtained when the “modified” ceramic membrane with pore diameter of 50 nm was used whit a significant increase of process productivity comparing the use of hydrophobic membranes. These results shows that membrane-protein interaction can be used to functionalize opportunely membranes to be used in membrane emulsification process reducing emulsification time and increasing dispersed phase flux without modify the control on droplets properties in terms of size and size distribution.

A simple mechanical method, by using turbulence static promoters, was used for increasing the shear-stress at the membrane surface while maintaining a low value along the circuit out of the membrane during cross-flow membrane emulsification process. Inside the lumen side of a tubular SPG membrane a turbulent promoter element was installed in order to increase the axial velocity at the membrane level where droplets are formed. In these conditions, the shear-stress of a cross-flow membrane emulsification was greatly increased at the membrane level, while maintaining a low value along the circuit. The system has been tested in the preparation of an oil-in-water emulsion. Results are compared with the conventional cross-flow membrane emulsification method. In the presence of insert reducer at high dispersed phase flux (30 l/hm^2), droplets size was reduced of 31% and droplets size distribution of 50% respect to the emulsion produced by cross-flow membrane emulsification in the same conditions of dispersed phase flux and continuous phase flow rate. The process was also tested in the preparation of high concentrated emulsions.

This study proves that emulsions can be produced by membrane emulsification with improved quality and fine-tuning properties reducing shear stress conditions and increasing dispersed phase flux. The work introduce innovative solutions insights in membrane emulsification that will enable the target development of membranes and process operative conditions for the application of membrane technology in the particles construction industry.

Keywords: Membrane Emulsification, Emulsions, reduced shear stress conditions, increased productivity